The 50 MHz DX Bulletin

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Understanding Solar-Terrestrial Reports

by Cary Oler, Solar Terrestrial Dispatch

2.5.5.1. The Slowly Varying Component

Radio frequency radiation from the sun has a characteristic minimum base-level which is generated by the thermal processes occurring in the sun. Over a period of days, this base-level radio emission can be observed to increase or decrease in intensity. These changes comprise the slowly varying component. In 1959, Covington[4] showed that the monthly average of the emission intensity varies in phase with the solar cycle. In fact, it was observed that the slowly varying component is closely associated with sunspots and plages.

Shortly thereafter, it was discovered that for the 20 cm radiation, the maxima of the solar radio emission represented the area overlying the brightest plage areas rather than sunspots.

Since the slowly varying component occurs at wavelengths ranging from 3 cm to over 100 cm, the range in height of the originating emission above the chromosphere can be considerable, from 10,000 to 300,000 km. At longer wavelengths, the slowly varying component begins to interact with radio bursts which originate higher in the corona. The greatest effect of the slowly varying component is observed over the frequencies of 7 to 60 cm.

The slowly varying component is not particularly important in determining potential terrestrial impacts such as geomagnetic storms. They are, however important in determining the potential activity and intensity of specific active regions (or of the entire visible solar disk as a whole). The solar flux (at a wavelength of 10.7 cm) represents the slowly varying component and is very useful in determining the activity of the sun as a whole.

2.5.5.2. Type I Bursts and Radio Noise Storms

Radio noise storms are violent increases in the intensity of noise originating from solar coronal regions. Noise storms are generally comprised of many (hundreds to thousands) of discrete bursts of noise, which have been identified and named as Type I bursts, or storm bursts.

Radio noise storms and Type I bursts are associated with the intense magnetic fields in active regions, which rise to coronal heights and interact with the corona to produce the noise.

Solar flares generally do not affect the frequency of occurrence of Type I bursts. They appear to be somewhat independent of flare phenomena and are correlated more with the magnetic fields in active regions than with flares.

These types of burst radiations are not of particular importance to those interested in predicting terrestrial impacts. For more information on these types of radio emissions, consult the many books available at your public or University library regarding flares and solar radio emissions.

2.5.5.3. Type III Radio Bursts

Type III radio emissions occur almost daily during the solar maximum years. Both Type III burst and Type V bursts are associated with fast drift events. Fast drift events are those where the frequency of the radio emission is observed to drift rapidly from higher frequencies to lower frequencies.

It has been determined that the drift rate is dependent on the frequency being observed. For example, the drift rate at 200 MHz is about 150 MHz per second, while the drift rate at lower frequencies such as 25 MHz is lower, near about 4 MHz per second.

These sweep frequency events are caused by outward-propagating waves which travel at high velocities ranging from 20% to 80% of the speed of light. The duration of most Type III bursts is about 30 seconds in the low frequency range, but varies with increasing frequency. Burst durations on the higher frequencies vary from 3 to 10 seconds at 100 MHz to less than 1 second above about 500 MHz.

Type III bursts tend to occur in groups, ranging from a single burst to as many as 100 grouped together. As the number of closely spaced bursts increases, the intensity of the observed emission likewise increases.

It has been determined that about 50 to 60 percent of Type III bursts occur within 10 minutes of the start of a flare or subflare. The greater the number of bursts in a group or the greater the intensity of a burst, the more probable the association with flares becomes.

Aside from the facts already stated, Type III bursts do not have any significant terrestrial impacts. They can enhance atmospheric ionization, but cannot produce geomagnetic storms.

2.5.5.4. Type V Radio Burst Emissions

Type V radio bursts tend to follow Type III radio bursts. This type of radiation consists of a wide-band emission of considerable intensity, particularly at the lower frequencies near 100 MHz, with durations from 30 seconds to 5 minutes. Type V bursts are usually confined to the lower frequencies, and have been observed from near 25 MHz to frequencies in excess of 150 MHz. However, most of the radiation remains confined to frequencies near 100 MHz.

Type V burst velocities average about 3000 km/second. They are very highly correlated with solar flares. Between approximately 60 and 90 percent of all Type V radio bursts occur within about 5 minutes of the start of a flare or subflare. They are more closely correlated with subflares than flares of greater importance, but are also frequently observed to occur in conjunction with flares of greater importance.

These radio emissions are not related to geophysical phenomena produced by large flares. There is no real correlation between these types of radio bursts and significant terrestrial impacts.

2.5.5.5. Type II Radio Bursts

Type II radio bursts represent slow-drift sweep frequency events. That is, the frequencies of the radio emissions decrease rather slowly when compared to the drift rates for Type III radio bursts. Type II radio bursts are important to solar terrestrial physicists, since their occurrence can increase the risks for terrestrial impacts, particularly if associated with Type IV burst emissions (discussed in the next section).

Almost all Type II events are coincident with flares, although most flares do not produce Type II bursts. In fact, Type II bursts occur rather rarely and are generally only associated with flares of greater importance (i.e.,. major flares).

These bursts consist of emission in narrow frequency bands that slowly drift from high to low frequencies. The average drift rate is about 300 KHz per second at 100 MHz. As a rule, the bandwidths of Type II bursts are quite narrow, sometimes only a few MHz in the lower frequencies near 100 MHz. Most slow-drift bursts of this type fade before reaching frequencies near 25 MHz, although Type II bursts have been known to drift down to frequencies below 25 MHz.

The drift of a burst from higher to lower frequencies may be interpreted as a result of the motion of the burst source through the corona. Methods have been adopted to calculate the approximate velocities of the burst sources through the corona. The methods relied on most heavily bring the average burst velocities to between 1000 and 1500 km per second. These values may be in error by a small amount, since the density of the coronal region where the burst source originated from must be used in the calculations and this value must be approximated from models of the corona, not from actual measurements.

Type II bursts are often associated with the expulsion of solar material into interplanetary space. By calculating the approximate velocity of the material using the method mentioned above, the approximate intensity of terrestrial impacts can be roughly determined. If the Type II burst is clearly associated with a well-positioned flare, the probability for increased geomagnetic activity increases dramatically. Moreover, it has been found that magnetic activity tends to increase between 1.5 and 2.5 days after the occurrence of Type II bursts. This correlates well with ejected material traveling at speeds near 1000 km/second.

2.5.5.6. Continuum Type IV Radio Emissions

Type IV radio emissions often follow the slow-drift Type II radio bursts. Type IV emissions are primarily stable emissions which do not drift in frequency very much (if at all). They have very wide bandwidths, sometimes more than eight octaves and often lie at higher frequencies than those occupied by most radio noise storms (see the section on Type I bursts). The greatest intensity of this radiation occurs at frequencies below 250 MHz. Often, Type IV emissions occur simultaneously at high and low frequencies in two separate areas of the spectrum. Type IV bursts frequently occur in the low frequency areas between 7 MHz and 38 MHz and very often follow Type II slow drift bursts.

A high percentage of Type IV bursts coincide with solar flares and burst emissions of Type II. Generally, Type IV bursts occur in conjunction with more powerful solar flares, which is also in agreement with the behavior of the Type II bursts which they often follow.

Further evidence of their association with major flares is the confirmed association with the occurrence of polar cap absorption events, where high energy solar protons penetrate into the Earth's atmosphere. They are therefore, also associated with the powerful proton flares and often accompany the expulsion of high-speed solar protons into interplanetary space.

The correlation between magnetic storms and Type IV events is exceedingly high when Type IV events are preceded by Type II radio bursts. In most cases, a Type II radio burst followed by a Type IV radio burst indicate the mass ejection of solar material into interplanetary space. This material most often causes geomagnetic storms within 48 hours of the observed event. Moreover, the association of a Type II followed by a Type IV radio burst is very highly correlated with the occurrence of major solar flares.

This is extremely helpful to the person interested in predicting potential terrestrial impacts caused by major flares. By calculating the velocity of the Type II burst and noting the intensity of both the Type II burst and the accompanying Type IV burst, the potential severity of terrestrial effects can be predicted with moderate accuracy. Given the typical lag time between flare occurrences and magnetic storms, the forecaster can generally foretell the occurrence of increased magnetic activity (and therefore radio propagation and ionospheric conditions) to within a 2 to 3 day period.

3. The Earth's Magnetic Field

All of the objects in our solar system have magnetic fields. The earth is no exception. We have used our magnetic field for centuries as a reliable tool in navigation. Little did we realize back then how vital our magnetic field is. Without a magnetic field, the earth would be subject to harmful radiations from the sun. Life probably would not exist as it does today.

The Earth's magnetic field has two poles. As any boy-scout knows, a compass points toward the north and south geomagnetic poles. But there is a third component of the magnetic field that most people are unaware of. This is a vertical component. Not only does a compass needle point north and south, but it also tilts at an angle to the horizontal plane. As one moves closer toward the magnetic poles, this "dip angle" increases towards the vertical. At the magnetic poles, a compass needle would point straight up and down and the horizontal movement (i.e.,. the movement pointing north or south) would be undefined.

If the magnetic field of the earth were drawn schematically on paper, it would resemble a spherical shell with lines of force propagating outward from the poles and connecting over the equatorial regions. This shape is characteristic for a spherical dipole magnet. A dipole field is a good approximation of the shape of the Earth's magnetic field. However it is not a perfect representation. Some anomalies from the perfect dipole exist. But for our purposes, a spherical dipole field will suffice in describing the phenomena which occur.

The solar wind has a profound influence on the shape of the Earth's magnetic field. The solar wind is analogous to winds that we experience here on earth, except that the winds are created by the outflow of energy from the sun. Just like the Earth's winds, solar winds can gust and fluctuate in speed. Solar flares can cause extreme gusts in both speed and pressure which can affect the stability of objects (such as satellites) in space.

The pressure from the solar wind transforms our Earth's magnetic field into a comet-like appearance. The "head" of the "comet" surrounds the earth and the "tail" extends outward away from the earth for millions of miles (well beyond the orbit of the moon). The region near the head of the magnetic field where the solar wind first makes contact with the Earth's field is called the bow shock region. This is a transition zone where particles of the supersonic solar wind are abruptly slowed to subsonic speeds. Particles and radiations can be deflected around the earth by this region. It therefore serves as a type of "shield", protecting us against certain harmful radiations.

The Earth's magnetic field is flexible, like a bed of springs. It reacts to increased solar wind pressure by compressing inward and reacts to decreased wind pressure by expanding outward. Strong solar wind gusts created by powerful solar flares are capable of compressing the Earth's magnetic field to altitudes near where geosynchronous satellites reside. Compressions of this magnitude generate enormous currents in the Earth's magnetosphere which in turn spawn powerful geomagnetic storms. These storms are closely monitored around the world. Moreover, fluctuations in the speed and density of the solar wind are also responsible for producing geomagnetic storms.

In the following sections, we will discuss the properties of geomagnetic storms, substorms, accompanying auroral activity and the combined effects on radio propagation.

3.1. Geomagnetic Substorms

When the conditions and characteristics of the solar wind change or fluctuate rapidly, the geomagnetic field can become disturbed. Instabilities also result when interactions with solar magnetic fields occur. Instabilities in the geomagnetic field often result in the generation of electrical currents in the magnetosphere and ionosphere which in turn, produce accompanying geomagnetic fluctuations detectable at ground level.

Geomagnetic substorms are relatively short-lived, lasting anywhere from less than 30 minutes to as much as several hours.

Substorms are most prevalent in polar and auroral-zone latitudes (latitudes above about 55° to 60° geographic latitude—although the zones are more a function of geomagnetic latitude than geographic latitude).

3.2. Geomagnetic Storms

When many substorms occur over a period of a day or two, the entire event as is called a geomagnetic storm. Intense geomagnetic storms may last many days, but most occur over a period of 24 to 48 hours.

Geomagnetic storms undergo three basic stages of development. These stages are outlined as follows.

First, a shock wave from the sun slams into the earth. This sudden gust and pressure change in the solar wind produces a magnetic impulse that is detected all around the world in a matter of minutes. This magnetic impulse is called a sudden storm commencement (SSC) or sudden commencement (SC). This marks the initial phase of a magnetic storms' development.

During the SSC, the intensity of the horizontal component of the Earth's magnetic field increases. This increased intensity is due to the sudden compression of the Earth's magnetosphere. During the next several hours, the magnetic field remains fairly steady with only minor fluctuations.

Approximately three to six hours after the SSC, the second phase or main phase of the storm begins. At this time, the Earth's magnetic field begins to fluctuate wildly. The main phase coincides with the arrival of the main cloud of particles that are ejected from major flares or coronal holes. It may take several days for the earth to pass through this cloud of solar debris. During this period, the earth can experience major magnetic fluctuations (substorms) all around the world.

Following the main phase is the recovery phase. This phase may drag on for days following the main phase. It is a period when the geomagnetic field begins to return to normal. When the extreme conditions in space abate, the magnetosphere begins to relax. This phase of recovery may still experience some periods of substorm activity, but overall activity noticeably decreases. Within several days, the geomagnetic field returns to normal and substorming ceases.

Not all geomagnetic storms follow these stages precisely. Many storms, for example, do not begin with a sudden commencement. Many storms simply enter the main phase gradually. These types of storms are called gradual commencement storms and are generally associated more with coronal holes than with energetic solar flares. They also tend to be less intense than storms which are associated with SSCs.

Occasionally, a sudden and short-lived shock impacts with the Earth's magnetic field. This sudden impulse (or SI) is usually a precursor to increased geomagnetic activity, although storms preceded by sudden impulses are usualy only of minor intensity (there are exceptions to this, however). Sudden impulses occur as very-short-duration (around four minutes) pulses of increased magnetic intensity. They are easily seen on magnetometer traces as distinct short-lived, relatively high amplitude "bumps".

3.3. Ionospheric Effects of Geomagnetic Storms

Geomagnetic storms can have a profound effect on the conditions in the ionosphere, particularly over the auroral-zone regions. Geomagnetic storms are usually caused by terrestrial interactions with solar-ejected clouds of particles. These clouds of particles are directed by the magnetic field toward the polar regions, but tend to congregate along an oval-shaped region known as the auroral zone. In this region, where the particle penetration is often the highest, ionospheric properties and characteristics fluctuate most rapidly.

Besides being the primary particle penetration boundary, the auroral zone is also associated with the strongest magnetic fluctuations and levels of instability in the world. These zones (one in the northern and one in the southern hemisphere), are located at approximately 67° geomagnetic latitude (which corresponds somewhat to geographical latitudes between roughly 55° and 70°). These zones often migrate equatorward as geomagnetic activity increases. Hence, for many middle-latitude locations, strong geomagnetic activity can place them directly in the heart of the auroral zone due to the migration of the auroral zone.

The ionospheric properties over the auroral zone can change rapidly. This zone is the home of the auroral electrojet, which is an oval-shaped core of intense electrical current which courses through the ionospheric and magnetospheric regions. This current (along with particle precipitation) can cause large temperature anomalies at ionospheric heights. The magnetic field and ionospheric densities at ionospheric heights sensitive to radio communications likewise, undergo large fluctuations and other anomalies which can affect radio propagation conditions.

The ionosphere basically consists of four distinct regions of ionization. These regions, called layers, are defined according to height. The lowest layer, called the D-region, resides at a height of about 70 to 90 km and appears only during the daylight hours when solar radiation is sufficiently high to ionize the ionosphere at these relatively low heights. The E-layer lies above the D-layer at an altitude between 90 and 150 km. This region, like the D-layer is primarily ionized during the day, but can remain ionized sufficiently to provide distant radio communications into the evening hours. The region above the E-layer is the F1 layer, which is located at a distance of between 150 and 250 km. During the day, this region is distinct and separate from the last layer of the ionosphere, the F2 region, which resides at an altitude which varies between about 250 and 400 km. During the late afternoon and evening hours, the F1 and F2 regions merge into a single region of ionization simply called the F-region.

Auroral activity and maximum energy deposition occurs in the auroral zone at a height of about 110 km. This coincides with the E-region of the ionosphere. During geomagnetic storms, the amount of ionization in the ionosphere over the auroral zone is often intense enough to absorb all radio signals which pass through that region. These polar blackouts are usually confined to the high latitudes and polar regions, but can slip southward with the expansion of the auroral zone equatorward.

One of the most pronounced effects of geomagnetic activity on ionospheric properties is the ability for VHF radio signals to be "bounced" from regions of visual auroral activity. During intense geomagnetic storms, the dip angle of the Earth's geomagnetic field at ionospheric heights over the auroral zone can deviate by several degrees. The deviation introduces a curvature in the dip-angle of the magnetic field which serves as an effective medium for bouncing VHF signals. The curvature, combined with the high levels of ionization near E-layer heights permits these high-frequency signals to be scattered by the ionospheric anomaly. This process is called auroral backscattering and is a primary source for long-distance VHF communications.

Geomagnetic storms also influence the maximum usable frequencies (MUFs) of the various ionospheric layers. The maximum usable frequency of the F2 region is affected most profoundly during geomagnetic storms. In most cases, the MUF decreases well below normal values at F2 layer heights. These heights happen to be most sensitive to HF long-distance communications. In some rare instances, however, the MUF of the F2 region actually increases during magnetic storms. The main phase of geomagnetic storms affect the MUF of the E-layer as well. Depressions in the MUF of the E-region are most often associated with large geomagnetic storms.

The ionization which occurs at E-layer heights is also responsible for another type of radio phenomenon known as sporadic E. Sporadic E occurs when cloud-like areas of enhanced ionization form at altitudes between about 90 and 150 km. These so-called "clouds" drift with time and are most prevalent during the daylight hours and during periods of geomagnetic storming over the auroral zones. Intense storming often causes abnormal increases in E-layer ionization, which can result in polar blackouts.

4. Radio Signal Propagation

Radio science rests on the discoveries of Ampere, Oersted, Faraday, and Henry, who developed the principles of electric induction and electric and magnetic fields surrounding conductors carrying current. A single unified electromagnetic theory was achieved between 1867 and 1873 by the Scottish physicist James Clerk Maxwell. In 1887, Heinrich Hertz discovered radio waves and showed that they exhibit all of the properties of light waves.

In 1896, Guglielmo Marconi assembled various items of equipment developed by Hertz, D.E. Hughes, Edouard Branly, Oliver Lodge, and others, and approached interested British party's with a proposal to use the Hertzian waves for commercial communications. In 1897, the Wireless Telegraph and Signal Company was formed for this purpose, and by the end of that year, messages had been sent over a distance of 18 miles. Between 1897 and 1899, Marconi developed equipment for tuning transmitters and receivers to the same frequency to avoid interference between stations and to conserve the power of the radiated waves. Shortly thereafter, in 1900, Marconi successfully transmitted a transatlantic message to anxious ears in North America.

Luckily, the ionospheric conditions at that time were favorable for transatlantic communications. It may have been quite a setback if their attempts at transatlantic radio communications had failed due to geomagnetic activity or solar flares.

Since that first transatlantic contact, we have significantly expanded our knowledge of ionospheric radio wave propagation. We have formulated models of ionospheric behavior in propagating radio waves and have learned of the types of solar phenomena which can have impacts on radio propagation. In this section, we will briefly examine some of the more important aspects of radio propagation as it deals with VLF, HF and VHF radio waves.

4.1. Propagation of VLF Signals

Very Low Frequencies (VLF) are those frequencies which range from below 1 KHz to approximately 150 KHz. These frequencies are home to the navigational beacons which transmit on these very low frequencies.

Radio signals in the VLF range are affected differently than those in the HF range. VLF signals are generally enhanced during solar flare induced SIDs (sudden ionospheric disturbances). Signal strengths of VLF signals have been found to increase, often quite dramatically, during solar flares. They also tend to become enhanced during the initial phase of geomagnetic storms, but may later suffer strong absorption during the main phase.

We will restrict our discussion of VLF propagation to the above, due to the inability of most people to use this band of frequencies for any useful communications. The bandwidth of VLF communications is insufficient to permit voice communications. Hence, this band of frequencies is not heavily used for day-to-day long-distance radio communications and is not of particular importance to us in this document.

4.2. HF Signal Propagation

The most widely used communications frequencies for long-distance communications are those which span the frequency range between 1.8 MHz and 30 MHz. At these frequencies, the ionosphere is capable of bending radio signals back toward the earth. This makes long-distance communications a viable possibility on the HF bands.

Radio propagation on the HF bands is most dependent upon geomagnetic activity, auroral activity (both of which determine the state of the ionosphere and which are most applicable over middle and higher latitude paths), and solar activity.

Solar activity can severely affect the propagation of HF radio waves through the ionosphere. Significant solar flaring can produce isolated temporary periods of radio blackout conditions. The intense levels of radiation which accompany strong solar flares ionize the Earth's ionosphere over sunlit portions of the earth and produce strong absorption levels capable of completely absorbing radio signals. Flare-related radio blackouts do not occur very frequently, however, and are limited only to the rare occasions when complex solar regions form and spawn flares of unusual severity.

When a major solar flare produces radio wave absorption over the sunlit portions of the earth, the phenomena is called a short wave fade (or SWF) and typically lasts between 20 and 50 minutes. Some long-duration events, however, can severely affect radio propagation for extended periods of many hours. These cases, however, are usually reserved for the large rogue flares which occur most frequently during the solar maximum years.

It is important to note that SWFs do not occur over the dark side of the earth. Although there is some evidence to suggest some subtle night-time effects, they are generally restricted to the daylight hours.

Strong solar proton flares frequently produce accompanying PCA and satellite proton events. As was mentioned earlier, PCA events have powerful effects on polar and high latitude radio communications. They are perhaps the most severe form of radio absorption that can occur over these latitudes. They can last for many days and can cause wide-spread polar blackouts on all radio frequencies. Their effects are not confined to the polar and high latitude regions, however. Strong events can migrate equatorward, and can engulf middle latitudes as well. Low latitudes are generally unaffected directly by PCA events. However, during periods of PCA activity, low latitudes are restricted in the latitudinal range where they can make radio contacts. They may be completely unable to establish contact with others at high or middle latitudes. They will almost certainly be completely unable to make contacts at polar latitudes. Likewise, signals which graze the PCA zone may be completely absorbed. HF transmissions during the daylight hours over low latitudes during PCA activity are generally weaker and less reliable. Higher powers usually do compensate, but may not aid in penetrating to long-distances. Night-time communications during PCA activity over low latitudes are usually not heavily affected. Therefore, there is a noticeable diurnal pattern of increased absorption over latitudes during periods of PCA activity. Basically, all latitudes are affected by PCA activity to some degree, although high latitudes and polar regions are by far affected the most.

Geomagnetic storms can be almost as devastating to high latitude and polar latitude radio transmissions as PCAs, although they are almost always less constant when compared to PCAs. That is, during geomagnetic storms, there will usually be periods of time where at least poor communications is possible. During PCAs, however, communications is often completely blacked out with very few (if any) opportunities for any HF propagation of radio signals.

During magnetic storms, auroral activity usually abounds in the high and polar latitude regions. Middle latitudes can also experience significant periods of strong auroral activity which can severely impact radio communications. During these periods, HF radio signals can become so garbled as to be completely unintelligible. Rapid fading of HF signals caused by auroral activity is called auroral flutter. Rapid fading and strongly erratic signal strengths over much of the HF spectrum can destroy attempts to communicate during auroral and geomagnetic storms.

Low latitudes are again, generally better off than higher latitudes during geomagnetic storms. They experience less fading, less absorption and less flutter. However, even low latitudes do not escape all of the effects of geomagnetic storming. Over all latitudes, the MUF of the F2 region decreases (often quite dramatically). Likewise, the MUF of the E region also often decreases. Also, the lowest usable frequency (LUF) almost always increases during a geomagnetic storm. The combined effects of decreased MUF and increased LUF effectively narrow the usable HF spectrum. Often, the F layer becomes completely unusable for HF communications, as has been observed many times with ionosonde maps of the ionospheric layers. The F region may completely disappears from such maps during some intense magnetic storms. At other times, there may exist spread-F which can also strongly influence radio communications over all latitudes. Spread F is caused by the scattering of radio signals by anomalies in the Flayer region. Spread F can limit the amount of information that can be transmitted long

distances and can also produce high fading rates, limiting the ability for long-distance radio communications. The usefulness of packet radio communications can be strongly affected by the occurrence of spread F.

Ionospheric conditions during magnetic storms vary considerably over small changes in latitude and longitude. These changes modify the character of radio signals which propagate through the changing layers of the ionosphere. Radio propagation over long-distances is therefore, difficult to accomplish with any reliability or success during magnetic storms.

Some very long-distance HF propagation has apparently been accomplished in the past during storm periods, but such contacts are not very common. HF radio signals are more likely to be severely distorted and/or absorbed by the anomalous ionization and magnetic behavior in aurorae than to be reliably propagated to long distances via aurorae. However, for the ambitious soul willing to attempt to establish auroral-contacts, note that your best chances are via CW. Voice communications via aurorae are for the most part, very unreliable, very unintelligible and suffer severe distortion and fading by the time they reach their destination. As will be seen in the following section, VHF radio propagation via auroral backscatter is a more reliable method of using aurorae for communications.

4.3. Long-Distance VHF Signal Propagation

Under most normal conditions, long-distance VHF signal propagation is next to impossible. Frequencies of 144 MHz are almost always well beyond the critical frequencies for the ionospheric layers. Attempts to transmit VHF signals long distances by the same means used for HF signals will prove fruitless in most cases. Frequencies transmitted to the ionosphere simply pass through it and out into space. Only under special conditions are VHF signals capable of being transmitted long-distances via ionospheric properties.

Probably one of the best known methods whereby this is accomplished is via sporadic-E. As was mentioned in previous sections, sporadic E occurs when isolated areas of enhanced ionization drift into the area. Radio signals of unusually high frequencies are able to be refracted or scattered by these localized “ionization clouds” back to the earth from E-region heights. These clouds are sporadic in nature. Hence any communications accomplished is likewise only temporary.

There are several other conditions that have yielded fairly good long-distance VHF communications. However, determining when these conditions will occur is almost as difficult as predicting sporadic E. Solar flares which produce SIDs often generate the enhanced ionization levels required for long-distance VHF communications. However, such communications are only possible over locations where SIDs are observed. SIDs occur only over the sunlit areas of the Earth. They also occur with less intensity over higher latitudes where the elevation of the sun makes a shallower angle with the horizon than at lower latitudes. Season therefore, plays an important role in the intensity, duration and frequency of SIDs for VHF propagation. Low latitudes generally have better luck in propagating VHF signals using the enhanced ionization produced during SIDs than high latitudes. Middle latitudes are also generally good for such types of propagation, but effectiveness decreases during the winter months due to the decreased elevation angle of the sun. High latitudes generally do not experience significant SID-related propagation possibilities on VHF frequencies during the winter months. However, the prospects improve dramatically during the summer months.

The only other major form of potential VHF communications takes place during auroral and geomagnetic storms. Propagation via aurorae on VHF frequencies is called auroral backscattering if long-distance contacts are made as a result of the radio signal bouncing off of the aurora. Likewise, forward scattering occurs when signals scatter off of the aurorae in a forward direction toward the polar regions. Two way auroral communications on VHF frequencies is called bistatic auroral backscatter communications.

It is important to note that “scattering” does not mean “refraction.” It means radio signals are literally scattered off of anomalies in the ionosphere near regions of auroral activity. Sometimes signals are scattered backwards. Sometimes they are scattered forwards. In rare cases where auroral geometry is just right, VHF signals can be scattered multiple times off of multiple aurorae to achieve significant long-distance communications. However, in these cases, the quality of the radio signal decreases dramatically with each contact of the scattering source.

Scattered VHF signals can be discerned by their very gruff, motoring sounds. These types of signals are affected by very rapid fading which often fade in and out at frequencies as high as 100 Hz. These signals are said to be sputtering or caused by auroral sputter.

In order to achieve auroral backscatter communications, auroral activity must be visible low in the horizon. The more intense the activity, the higher the probability for achieving long-distance backscatter communications. Directional antennas are a definite asset, since most of the power of the transmitter must be directed toward the auroral region. The auroral region must be at a low elevation angle in order to provide the geometry required for backscattering to occur. The distance of transmissions also increases with increasing distance to the aurora. Hence, low transmission angles are required. The prospects for distant bistatic auroral backscatter communications increases if CW communication is used. CW is much more intelligible when distorted by aurorae than is voice and therefore can be understood even when severely distorted by auroral activity.

The probability of achieving auroral backscatter communications is a function of latitude and geomagnetic activity. Lower latitudes do not experience auroral backscatter communications nearly as often as northerly middle latitudes and high latitudes where auroral activity is more prevalent. However, even at these higher latitudes, such communications depends on the extent of magnetic activity.

It has been found that auroral backscatter communications only become widespread during major geomagnetic storms. Minor geomagnetic storms are capable of providing conditions necessary for isolated auroral communications, but generally the best communications possibilities occur when geomagnetic conditions reach major storm levels (i.e.,. magnetic K indices of 6 or greater).

Backscatter communications have two well defined diurnal peaks. The largest peak typically occurs in the late afternoon/early evening hours. This peak is not quite so dependent on geomagnetic activity, although it does appear to be somewhat sensitive to it. The second peak occurs near local midnight, which coincides with the peak of auroral activity over most locations. This second peak appears to be heavily dependent on geomagnetic activity. Widespread backscattering has been known to occur during this second peak during periods of major geomagnetic storming. During quiet magnetic periods, the peak is almost non-existent, indicating only very rare and isolated incidents of backscatter communications.

From the foregoing, it is clear that long-distance VHF propagation is indeed possible, but requires special conditions before DX communication can occur. The best times for DX are in the late afternoon and early evenings. The next best opportunities come near local midnight during minor to major geomagnetic storms. Generally, the prospects for DX increase with geomagnetic activity. This is in sharp contrast to HF communication, which is seriously eroded during periods of high geomagnetic activity.

5. Characteristics of Auroral Activity

The Northern Lights (aurora borealis) or the Southern Lights (aurora australis) - hereafter referred to as aurorae - are beautiful, shimmering displays of lights in the skies. These lights have been a source of wonderment and awe for centuries. They are without a doubt, one of the most awesome displays of natural beauty known to man.

Aurorae are caused by high-speed, high-energy protons and electrons which collide with atmospheric atoms of oxygen and nitrogen. These bombardments cause the gas in the ionosphere to become ionized and give off photons of light. The “fluorescing” gas is not unlike the gases in a fluorescent light bulb, which also

become ionized and give off light when excited. Aurorae generally form at an altitude of about 100 km, within the E-region of the ionosphere. Occasionally during intense auroral storms, the lower boundary of the visible auroral forms dips down into the D-region heights slightly below the 90 km level. The height at which aurorae occur enables them to be seen for hundreds of kilometers before the curvature of the earth, light pollution, geographical obstructions or atmospheric anomalies blocks their view.

The complete morphology of aurorae is complex and beyond the scope of this document. Suffice it to say that the particles which penetrate into the atmosphere are directed by the Earth's magnetic field and that the main penetration belt coincides with the auroral zone. For more information, the interested reader is directed to the many available books on aurorae and magnetic storms.

5.1. Auroral Relationship with Geomagnetic Activity

Auroral activity is invariably linked with geomagnetic activity. Magnetic storms are always associated with auroral activity. Moreover, auroral activity is proportional to the intensity of magnetic storms. Increasingly intense magnetic storms yield increasingly intense auroral activity.

The intensity of an aurora depends on several factors. Auroral brightness, aerial extent, latitudinal extent, frequency of changing forms, pulsations and color changes are all used to determine the relative intensity of auroral activity. We say "relative intensity" because the intensity of an aurora is relative to the observer making the observation, and his or her experience in doing so.

Aurorae are most frequently seen at areas that reside in or near the auroral zone, a boundary where aurorae form most frequently. Global geomagnetic activity is also highest in this zone. The locus of auroral activity has been determined to reside near a geomagnetic latitude of about 67°. Areas between approximately 65° and 70° geomagnetic latitude are generally considered to be within the auroral zone (with some diurnal exceptions which will not be considered here).

The auroral zone contains the electrojet, an area within the auroral zone where high electrical currents surge through the ionospheric and magnetospheric regions. This electrojet is responsible for the majority of magnetic perturbations which occur in that region. The particularly strong anomalous behavior of the electrojet (as well as other current systems) during magnetic storms is what causes the intense magnetic fluctuations which are observed in and near the auroral zone. Even during periods of quiet magnetic activity, fluctuations in the auroral zone can be many times greater than fluctuations outside of the zone.

It is now clear that the auroral zone carries more meaning than simply the definition of the zone where aurorae occur most frequently. It is also the zone where magnetic activity is highest, where particle penetration into the atmosphere peaks, where anomalies of the ionosphere are most severe, and where atmospheric electrical induction becomes most pronounced.

Auroral activity in the auroral zone does not usually become distinctly visible until the geomagnetic field becomes unsettled. The threshold for observing auroral activity increases with increasing distance equatorward of the auroral zone. For example, middle latitudes generally require at least active geomagnetic conditions before any auroral activity can be discerned over the horizon. Minor storming usually provides good opportunities for auroral observations at middle and high latitudes. Low latitudes are generally incapable of viewing the auroral activity until major to severe geomagnetic storms occur. During periods of major geomagnetic storming, the auroral zone migrates equatorward and often resides over the Canada/U.S. border and into the northern U.S.. These periods are usually associated with sustained K-indices of six or more over the middle latitudes. With increasing activity, the visibility of auroral activity becomes possible at progressively lower latitudes.

It should be noted that the behavior of the southern auroral zone is no different than the northern auroral zone. Therefore, areas of Australia, New Zealand, etc., can apply these characteristics equivalently.

5.2. Significance of Aurorae to Astronomers

Considering the intrinsic brightness of aurorae, their occurrence can be an annoyance to astronomers. Bright aurorae associated with strong magnetic activity can obscure most of the sky. Moreover, their brightnesses can easily exceed the brightness of most stars. Aurorae therefore, pose as a threat to the observing astronomer.

Astronomers usually attempt to get as high above the atmosphere as possible to observe stars. However, even above all of the clouds and major atmospheric constituents, auroral activity can remain an annoying interference since their occurrence in the atmosphere is at an altitude of between 90 km and several hundred km's. Luckily, however, most of the high-altitude observing sites are in the low latitude regions, where aurorae occur relatively infrequently.

Aurorae can, on the other hand, be a real treat for the astronomer who searches for them and enjoys observing them. Aurorae can provide a significant amount of excitement. The activity in aurorae is often remarkable. Huge and rapid changes in color, brightness and form can all contribute to the spectacular events which can be observed in aurorae. Activity peaks when aurorae are seen directly overhead. Large, wavelike pulsations of light become easily visible when seen overhead. These flaming aurorae are often intensely bright and are constantly in motion. Bursts of auroral activity (associated with magnetospheric substorms) can dramatically increase the brightness and intensity of auroral activity within minutes. The combined brightness of auroral activity during intense auroral storms often surpasses the light given off by the full-moon. It is no wonder many astronomers often greet auroral activity with smiles and cheers.

5.3. Auroral Classifications

There are several ways of classifying aurorae. They can be classified according to shape, brightness, activity and even color. For most purposes, however, classifications according to shape and activity are enough.

Aurorae can occur in a near-infinite number of shapes and sizes. There are, however, forms which are more commonly seen. These forms have been given names to help identify them.

The zenith aurorae is best known near and in the auroral zones where aurora are seen throughout the sky, and directly overhead. As it implies, zenith aurorae are aurorae which occur directly overhead. They appear as a closely packed cluster of "beams" or "rays" which often change rapidly in shape, brightness and orientation. They often appear almost three-dimensional and are one of the more active forms of aurorae. The color of zenith aurorae vary considerably with time. Rapid and intense color fluctuations are often associated with these type of aurorae.

A well known auroral form is the curtain aurora. These aurorae are observed away from the zenith (either to the north or the south) and resemble curtains or drapes hung from the sky. They often change in shape moderately quickly. Particularly intense segments of curtain aurorae often drift eastward or westwards. The direction of drift is closely related to the time that the observations are made. Unlike the zenith aurorae, curtain aurorae are a relatively stable form that may persist for hours (although their shapes may change continually throughout their existence). The color of curtain aurorae vary, but are most often seen as greenish-white with occasional tinges of red or pink.

Closely related to the curtain aurora is the flaming aurora. Flaming aurora are basically curtain aurora which pulsate rapidly in brightness. The pulsations take on wave-like characteristics which resemble flames of fire. The wavelike pulsations propagate from the curtain aurora upward toward the zenith from all directions. Often, these pulsations converge at the zenith where diffuse aurora of pulsating shapes become visible. The flaming aurora have been mistaken for huge fires occurring in distant lands by people in the

times of the Roman Empire. There was one instance where a Roman Emperor sent out men and equipment to find and extinguish a fire they thought had engulfed a distant castle. Little did they know that the fire was a flaming aurora associated with a strong magnetic storm.

The pulsating aurora is a general term applied to auroral shapes which exhibit pulsations. Pulsating aurora do not generally occur until geomagnetic activity reaches minor to major storm levels. They are characteristics of intense ionospheric ionization and tend to coincide closely with magnetospheric substorms (i.e.,. periods of intense magnetic fluctuations and enhanced auroral activity).

Diffuse aurorae are most prominent during periods of low to moderate geomagnetic activity. They are usually the first to be seen prior to auroral and magnetospheric storms. During periods of persistent magnetic activity, diffuse aurorae may remain visible for days over the horizon. High latitudes are usually able to discern shapes, patterns and or slight pulsations in diffuse aurorae, but such activity is usually of low intensity. These types of aurora are generally inactive and dull forms of auroral activity.

Auroral arcs are moderately bright ropes of light that arc across the sky. They can form near the boundary of the auroral zone and the subauroral zone (the region just outside of the auroral zone). Arcs are generally relatively inactive and don't usually exhibit pulsations or rapid color fluctuations. They do, however, undergo occasionally large changes in brightness. The brightness intensifications usually precede periods of enhanced auroral and magnetic activity. The arcs are therefore, often good for indicating when enhanced auroral activity might be expected. The time between an arc brightening and enhanced auroral activity may range from under less than one minute to more than five minutes. Their brightenings are, however, well correlated with increased auroral and geomagnetic activity coinciding with magnetic substorms.

These are the major forms of auroral activity which are observed. Although these definitions do not nearly encompass all of the possible forms of auroral activity (each auroral event can differ from others), they encompass most of the major types of common auroral structures. For a definition of the classification of auroral activity, consult the document "Glossary of Solar Terrestrial Terms" available upon request from: oler@hg.uleth.ca.

6. The Impacts of Geomagnetic Storms and Solar Activity

Severe geomagnetic storms are relatively rare, occurring most frequently during the maximum of the solar cycle and least frequently during the minimum of solar activity. They are strongly correlated with major solar flares, which explains their solar cycle dependence.

Magnetic fluctuations during severe geomagnetic storms often surpasses 2,000 nanoTesla (gammas), which is the smallest, most commonly used unit of measuring magnetic field strengths. Fluctuations this large over a period of minutes is enough to cause significant effects to terrestrial ground-based systems. Industries which can be hit particularly hard are the electrical generation utilities, communications networks, and companies managing large pipelines or other long conductive objects. Recent research is also revealing a causative relationship between large geomagnetic storms and changes in atmospheric circulation.

In the following sections, we will attempt to cover some of the relationships between strong geomagnetic storms and impacts with these terrestrial systems. We will also point out some of the more important research which has been done with regards to solar and geophysical activity on atmospheric circulation. It should be noted that some of the following material may be considered inconclusive and still under research.

The reader is warned that the material which follows is of a technical nature and therefore may not be clearly understood. An attempt will be made to pad the discussion with sufficient references to provide a respectable background of information with regards to the following discussions. Please note that the following material is not essential to the understanding of the solar terrestrial reports. It may, therefore, be skipped by those who are not interested in the potential impacts of solar and geophysical activity on terrestrial systems and the environment.

The discussion below has been separated into two main sections. The first section discusses the impact of magnetic storms on very long ground-based conductive objects such as electrical power lines, pipelines, railway networks and telecommunications networks. The principles discussed apply to most of these fields. Emphasis is placed on the electrical power generation industry, which can strongly affect the terrestrial community as a whole. The second section discusses the impact of severe magnetic storms and strong solar flares on atmospheric circulation, which is still in a "gray" area with regards to conclusiveness.

6.1. Magnetic Storm Induction

The principle by which intense magnetic fluctuations induce currents into long conductive objects has been extensively studied over the last several decades. The principles are well understood and have been extensively verified by numerous researchers.

During major to severe geomagnetic storms, the geomagnetic field exhibits very strong fluctuations in intensity. These fluctuations are caused by strong electrical currents residing in the ionosphere and deep inside the Earth. During these storms, electrical currents are able to flow through the grounded neutral lead of large power transformers and into the power system. These induced currents in the neutral lead causes additional magnetic fields to develop and reside in the core of these large transformers. The presence of these magnetic fields in the core of the transformer produce spikes in the AC waveform in the transformer (caused by the addition of the normal magnetic fields with the induced magnetic fields). These spikes produce harmonics which can trip protective relays. They also cause the transformer to operate less efficiently. This lack of efficiency can significantly increase the amount of current drawn by the transformer, effectively placing an additional load on the power system. If the harmonics occur for a sufficiently long period of time, physical damage to the transformer can occur.

For example, the major magnetic storm of March 13 and 14, 1989 induced electrical currents on many of the electrical power distribution networks in Canada. Induced currents measured by Ontario Hydro during this storm were about 80 amperes/phase. Newfoundland and Labrador Hydro Electric Utilities witnessed geomagnetically induced currents as high as 150 amps/phase. Hydro Quebec experienced magnetically induced currents powerful enough to saturate transformers. The transformer saturations generated harmonics which tripped protective relays on static compensators. The loss of power caused by these events (of near 9,450 Megawatts) overloaded the rest of the system within seconds and resulted in a total collapse. The ensuing power blackout lasted about nine hours and affected over six million people in Quebec. This storm had many effects on the electrical power industry. Many stations experienced numerous power fluctuations, voltage depressions and surges.

The effects of geomagnetic storms on long conductive objects have been studied since the beginning of this century. Since then, many authors have elaborated on the characteristics and principles whereby such phenomena occur. For a good (although technical) discussion of these principles and characteristics, consult the papers by Campbell[5] , Watanabe and Shier[6] , Anderson et. al.[7], Lanzerotti and Gregori[8] , P.R. Barnes and J.W. Van Dyke[9] , D.H. Boteler[10] , and again by D.H. Boteler.[11]

In previous years, telecommunications cables have been damaged by magnetic storms. Damage was reported in 1958 and again in 1972 during severe geomagnetic storms. These lines were made of conductive metal and carried magnetically-induced currents through the lines to equipment connected to them. The damage sustained in previous years has been large, despite methods to protect them against induced currents. Recently however, transatlantic telecommunications cable has been replaced with fiber-optic lines, which are not conductive. During the major magnetic storm of March 1989, the fiber-optic cable itself sustained no damage and experienced no problems. However, the power supply

lines which accompany the fiber-optic cables and are conductive, sustained damaging voltage surges as high as 700 volts during the March 1989 magnetic storm.

Pipelines experience the same kinds of damaging effects as occur on power lines and telecommunications cables. Protective equipment on pipelines are used to prevent rogue surges from damaging the pipelines through excessive electrolytic corrosion at weak points in the pipeline coating. During the March 1989 storm, these protective systems were rendered useless on many pipelines due to the excessive currents which were produced during the storm. Some electrolytic corrosion undoubtedly occurred on many pipelines as a result.

The effects of strong geomagnetic storms on terrestrial systems is well known. The power and magnitude of their influence can, at times, be remarkable (as was manifest by the large power blackout in Quebec during the last severe global geomagnetic storm). Industry is slowly devising ways and equipment to cope with strong magnetic perturbations, but is still a long ways away from immunity to such natural events.

6.2. Atmospheric Circulation Modifications

For decades, researchers have been attempting to determine whether large solar events and correspondingly large geophysical activity affect the global atmospheric circulation of the earth. A great deal of research has been done in this respect, and further research is still needed in order to qualitatively confirm anomalies produced by any geophysical or solar activity. In this section, we will touch on some of the aspects of geophysical and solar activity which apparently have been well-correlated with changes in atmospheric circulation. The physical mechanisms for such changes are not well known, and certainly in many cases are still heavily disputed. However, the correlations achieved in previous research cannot be easily dismissed. We therefore, expect the reader to understand the nature of this section and treat it as inconclusive, yet correlated evidence. For more information, we trust the interested reader will consult the papers and publications cited herein.

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(To be continued)

POSTSCRIPT FROM K6FV

I hold nightly schedules with ZK1AA and FO5DR. Rene Delamare, FO5DR (who also operates a 50 MHz beacon), regularly monitors TV video carriers, mainly from stations in the Hawaiian Islands. He also listens for the KH6HME, KH6HI, and K6FV six meter beacons. The following table lists the times he observed Trans-equatorial propagation (TEP) during June and July 1992. The times (in UT) are approximate, especially for the upper channels; e.g., his report may read "three hours of TEP on channels 2, 3, & 4 and KH6 beacons starting at 0630." Activity was down in June and July compared to earlier months.

Date	KH6bcns	Channel 2	Channel 3	Channel 4	K6FV
0617		0600-0800		0600-0800	
0628	0605-0805	0600-0805			
0708	0545-0845	0545-0845			
0709	0640-0710	0640-0710			
0710	0615-0715	0615-0715			
0716	0615-0915	0615-0915			0650
0730	0630-0830	0630-0830	0630-0830	0630-0830	0730

I have been receiving daily ionospheric summaries by e-mail from Solar Terrestrial Dispatch and would like to share with you the values of f_oF_2 measured by an ionospheric sounder at Keakawapu HI (N20W156) during July 1992. (Some days are missing, the data was not sent (or received). I am showing only those values between 00 and 10Z, as this period covers the afternoon and evenings peaks.

The ratio of the MUF to f_oF_2 can range from just under 3 for 3000 km paths to perhaps 4 or more for scatter or long earth-detatched paths, especially across the geomagnetic equator. Thus a f_oF_2 of 10 MHz indicates that 10 meters should be open for paths whose reflection point is at the same geomagnetic latitude and local time as the sounder. A f_oF_2 exceeding 12.5 MHz indicates possible six meter openings, and a f_oF_2 exceeding 16 MHz indicates likely strong openings for properly located 50 MHz stations.

The following descriptive codes may appear in place of f_oF_2:

A = Blanketing Sporadic E
B = Complete Absorption
C = Equipment Problems
D = Frequency Higher than Equipment
E = Frequency Lower than Equipment
F = Spread Echoes
G = FOF2 is less than FOF1
I = Smoothed Value
R = Attenuation

JUL	0	1	2	3	4	5	6	7	8	9	10Z
1	12.5	11.6	12.0	12.0	10.5	9.1	8.7	8.4	8.0	7.7	7.9
2	11.1	11.8	13.0	12.0	11.0	10.6	9.1	8.2	8.7	8.4	7.8
7	10.4	10.8	12.0	12.6	12.0	10.4	9.8	9.6	9.5	9.7	9.0
8	11.3	12.2	12.9	12.2	9.9	8.6	8.7	8.9	8.1	9.4	9.7
9	10.7	11.3	11.5	C	C	11.0	9.5	9.5	9.6	9.6	9.7
10	11.7	11.6	11.7	12.0	11.1	10.5	9.8	10.0	10.2	9.9	10.6
11	11.6	11.6	11.7	12.2	13.0	12.5	11.5	11.5	11.9	11.3	9.7
12	11.4	11.7	12.5	14.5	13.4	10.7	9.5	9.8	9.1	9.2	11.2
13	11.4	11.7	12.5	14.5	13.4	10.7	9.5	9.8	9.1	9.2	11.2
14	9.0	11.1	11.7	11.8	10.4	8.0	7.9	8.0	7.6	7.3	7.2
15	10.5	11.1	12.0	12.7	11.7	10.6	9.5	9.3	9.3	9.1	8.6
16	10.0	10.6	11.7	13.4	14.0	11.0	10.9	11.3	12.0	12.4	12.7
17	10.8	10.9	11.6	12.4	12.0	11.0	8.4	7.9	8.1	8.0	7.4
18	11.0	11.5	12.1	11.1	10.6	10.0	9.8	9.5	9.3	8.8	8.8
19	A	12.7	14.2	15.0	15.0	13.2	11.6	11.2	11.7	11.4	10.7
20	11.6	11.1	11.7	13.0	14.7	10.9	9.0	8.7	8.7	8.3	8.0
21	10.7	11.2	11.6	12.1	11.0	8.8	8.3	7.7	7.5	7.6	7.3
22	10.2	12.0	10.9	10.5	10.5	11.7	10.0	8.4	8.7	9.9	9.0
23	9.6	8.1	8.4	9.7	10.9	11.2	9.7	6.7	5.2	5.7	5.1
24	8.8	9.5	9.8	10.7	10.7	A	6.0	6.4	6.2	6.6	6.8
25	11.0	11.9	13.0	13.0	10.7	9.3	7.0	6.4	6.0	6.1	6.2
26	10.3	11.0	12.0	13.0	12.4	9.4	5.9	6.0	6.0	5.7	5.5
27	11.6	10.5	10.4	10.6	10.5	10.2	8.5	7.8	7.4	6.4	5.6
29	10.1	10.9	10.6	11.4	9.7	8.6	6.0	5.2	5.1	4.9	6.2
30	12.7	13.0	13.5	14.0	13.2	11.1	8.4	6.9	6.3	6.2	6.1
31	10.5	10.7	11.1	10.2	8.2	7.8	7.2	5.5	5.2	5.3	5.2

Note that the f_oF_2 at Keakawapu HI may be as low as 6.3 MHz (or as high as 12.4 MHz) during >55 MHz TEP between Tahiti and Hawaii. Admittedly, the reflection point(s) may lie 2000 km south of Keakawapu HI, but in my opinion there is not sufficient ionization along the path for classical F_2-layer propagation modes. Clearly, night time TEP is a scatter mode.

On an average day, ionospheric data (f_oF_2, M(3000)F2, and TEC) are sent for 5-10 stations in the Northern Hemisphere. I would like to share some of this data with you in future issues.